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THERMAL ANALYSIS OF THE MC1 ENGINE TURBOPUMP

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ABSTRACT

The MC1 Engine turbopump supplied the propellants to the main injector. The turbopump consisted of four parts; lox pump, interpropellant seal package (IPS), RP pump and turbine. The thermal analysis was divided into two 2D finite element models; Housing or stationary parts and rotor or rotating parts. Both models were analyzed at the same boundary conditions using SINDA. The housing model consisted of; lox pump housing, ips housing, RP housing, turbine inlet housing, turbine housing, exit guide vane, heat shield and both bearing outer races. The rotor model consisted of the lox impeller; lox end bearing and id race, RP impeller, and RP bearing and id race, shaft and turbine disk.

The objectives of the analysis were to (1) verified the original design and recommend modifications to it, (2) submitted a thermal environment to support the structural analysis, (3) support the component and engine test program and (4) to support the X34 vehicle program.

INTRODUCTION

The MC1 Engine turbopump supplied the propellants to the main injector. The thermal analysis was divided into two 2D finite element models; housing or stationary parts and rotor or rotating parts. Both models were analyzed at the same boundary conditions. The housing model consisted of; lox pump housing, ips housing, fuel housing, turbine inlet housing, turbine housing, exit guide vane, heat shield and both bearing outer races. The rotor model consisted of the lox impeller, lox end bearing and id race, fuel impeller, and fuel bearing and id race, shaft and turbine disk.

OBJECTIVES

The objectives of the analysis were to (1) verified the original design and recommend modifications to it, (2) submitted a thermal environment to support the structural analysis, (3) support the component and engine test program and (4) to support the X34 vehicle program.

DESIGN CONFIGURATION

The design configuration of the MC1 turbopump was to supply the propellants to the main injector using the turbine energy supplied by the gas generator. The turbine inlet housing is connected by bolted flange to the gas generator. The turbine exit diffuser was bolted to the turbine discharge duct. The lox pump inlet was connected to lox tank feed line. The lox pump discharge was bolted to the discharge line which it was connected to

the lox main valve. The fuel pump inlets are connected to fuel tank feed line, which it was divided into two lines for the two inlets of the pump. The fuel pump discharge was bolted to the discharge line, which was connected to the fuel main valve.

A lox secondary flow was required to maintain the lox pump end bearing at a low temperature during operation. A fuel secondary flow was required to keep the turbine end bearing at a low temperature during operation. Both flows are recirculated from the high pressure side of the pump, through a small line into the bearing cavity back to the main flow on the low pressure side of the pump.

The interpropellant seal package was design to maintain a positive pressure differential between the lox bearing cavity and the fuel impeller back face. This was achieved by using high pressure helium as a medium between the cavities and the used of a series of carbon seal and knife edge seals helped to keep the flow leaks to a minimum.

The turbine was composed of the turbine inlet manifold, 24 converging/diverging nozzle, the disk, 147 blades, and 67 turbine guide vanes. The pumps are both single stage shrouded impellers. The shaft is supported by two ball bearing packages, one at the lox pump end, behind the impeller, the other at the turbine end, between the fuel impeller and the turbine.

As a result of the analysis a heat shield between the disk cavity and the fuel pump housing, and a radial pin joint, a minimum contact attachment, between the fuels pump housing and the turbine inlet housing were implemented into the base design.

DESIGN REQUIREMENTS

The global design requirement condition were base at steady state conditions and full power level. They were also several specific conditions in the design related to the thermal analysis. The clearance between the fuel pump housing and the outer race of the turbine end bearing or bearing deadband was required not to exceed a limit of .002 inches during operation. The operating temperature of the bearing and races were limited to a specific range. The temperature of the fuel fluid was limited to be above its freezing point, introducing the necessity of heaters.

The X34 environmental conditions, the flight conditions of hot and cold day, the ability of start and operated at high altitude (low ambient air), and the iteration between the turbopump ant the engine compartment were parts of the design requirements

THERMAL ANALYSIS

The analysis consisted of two finite element models; housing assembly and rotor assembly. They were solved using the SINDA thermal analyzer computer code. Cold day and Hot day X34 vehicle conditions, as predicted by OSC, were used for the environmental ambient conditions, air temperatures flow conditions, etc. These conditions varied with time from time zero, ground, to flight back

The internal pump environment was predicted by Brian Goode from time 18000 seconds from engine start, which included ground time, airplane flight until lox pump chilldown. During engine chilldown heaters were used to keep the intefuelropellant housing temperature above the freezing temperature (-40 F°) of the fuel.

At engine start, time 0, boundary conditions were based on the fuel reach start conditions predicted by Mike Martin of the System Analysis Group, Space Transportation Directorate, also for engine hot firing max. conditions as well as engine cut off time, 150 sec., and shutdown. Internal flow Conditions were supplied by Katherine Van Hooser of the Functional Design Group of the Space Transportation Directorate.

Housing Model

Transient axisymmetric thermal analysis ran in SINDA thermal solve. The was generated from a 2D finite element mesh obtained from Wayne Gregg of the Strenght Analysis Group. The model consisted of 13747 nodes and 51547 conductors. The thermal boundary conditions were applied in Patran. Corrected mass and conduction areas were simulated for exit guide vanes, radial pins, heat shield bolts, and bolt washers. Results were obtained for all X34 flight conditions. Figure 1 shows some of these results. Figure 1 shows the thermal gradient at the turbine inlet wall during the engine start transient. It reached steady state conditions on about 10 seconds.

A requirement of .002 inches, maximum turbine end bearing deadband was imposed by the rotodynamic analyst to maintain stability on the bearing. The following design changes were implemented to reach this requirement. The heat shield insulating the pump housing from the hot turbine environment, and the turbine inlet housing to pump housing joint pin which reduced the heat transfer between the hot turbine inlet and the pump housing. The heat shield reduced the heat transfer between the turbine hot gas and the pump housing.

The bearing temperature control is a critical issue on the thermal design of the turbopump. Mass averaged outer race temps were calculated and provided to Tim Jett of the Nondestructive Evaluation & Tribology Group for the bearing design. Simulation included flow through the bearing, which keep the outer races at fluid temperature. Maintaining the outer race at the same or closed temperature as the fluid and housing kept a constant gap between the outer race and the pump housing during the mission.

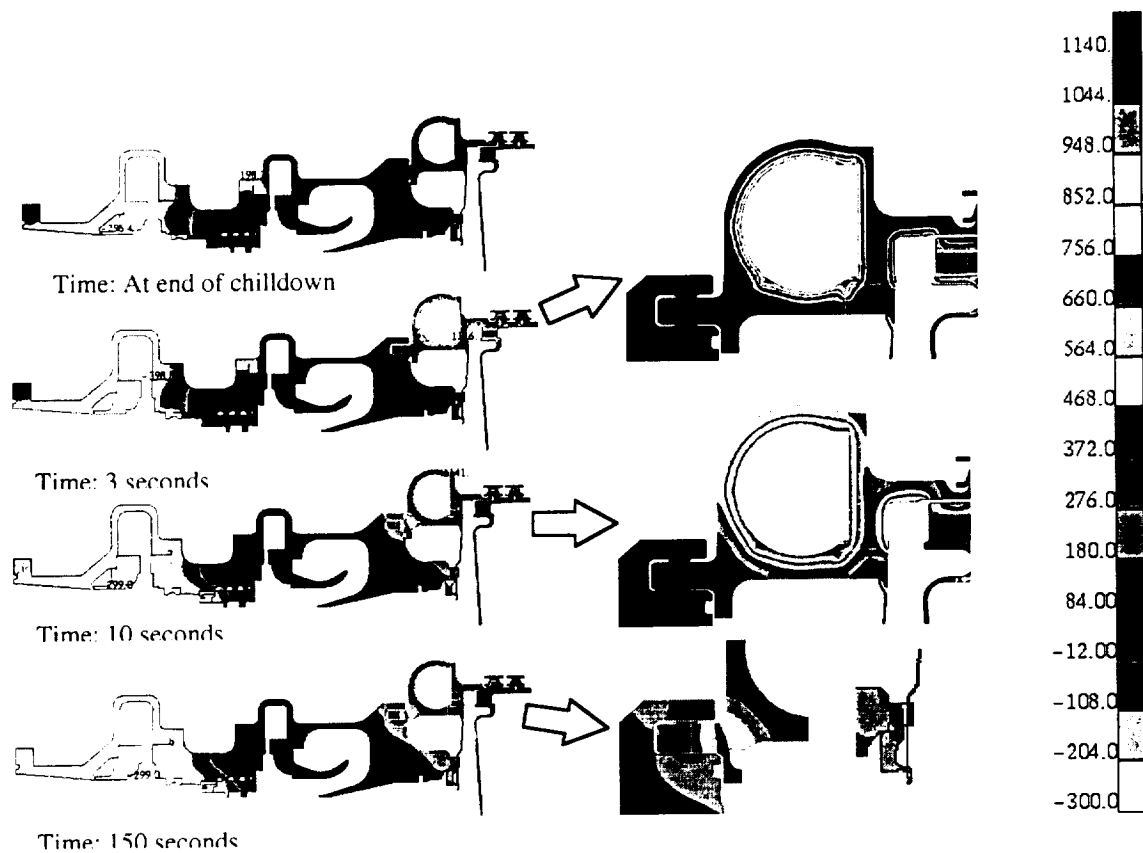


Figure 1 Composite of Housing Transient Result

Rotor Model

Transient axisymmetric thermal analysis ran in SINDA. The model was generated from a 2D finite element mesh. The model consisted of 3125 nodes and 12331 conductors. The thermal boundary conditions were applied in Patran. Corrected mass and conduction areas were simulated for pump impellers, ball bearings, and turbine blades.

Results were obtained for all X34 flight conditions. Figure 2 shows some of these results. Figure 2 shows the thermal gradient at the turbine disk during the engine start transient. The long period of heat soak represents the flight back time of the X34 vehicle after engine shutdown. The analysis is required due to the possibility of bearing clamping between the housing and the rotor assembly due to the difference on the heat dissipation between both hardware.

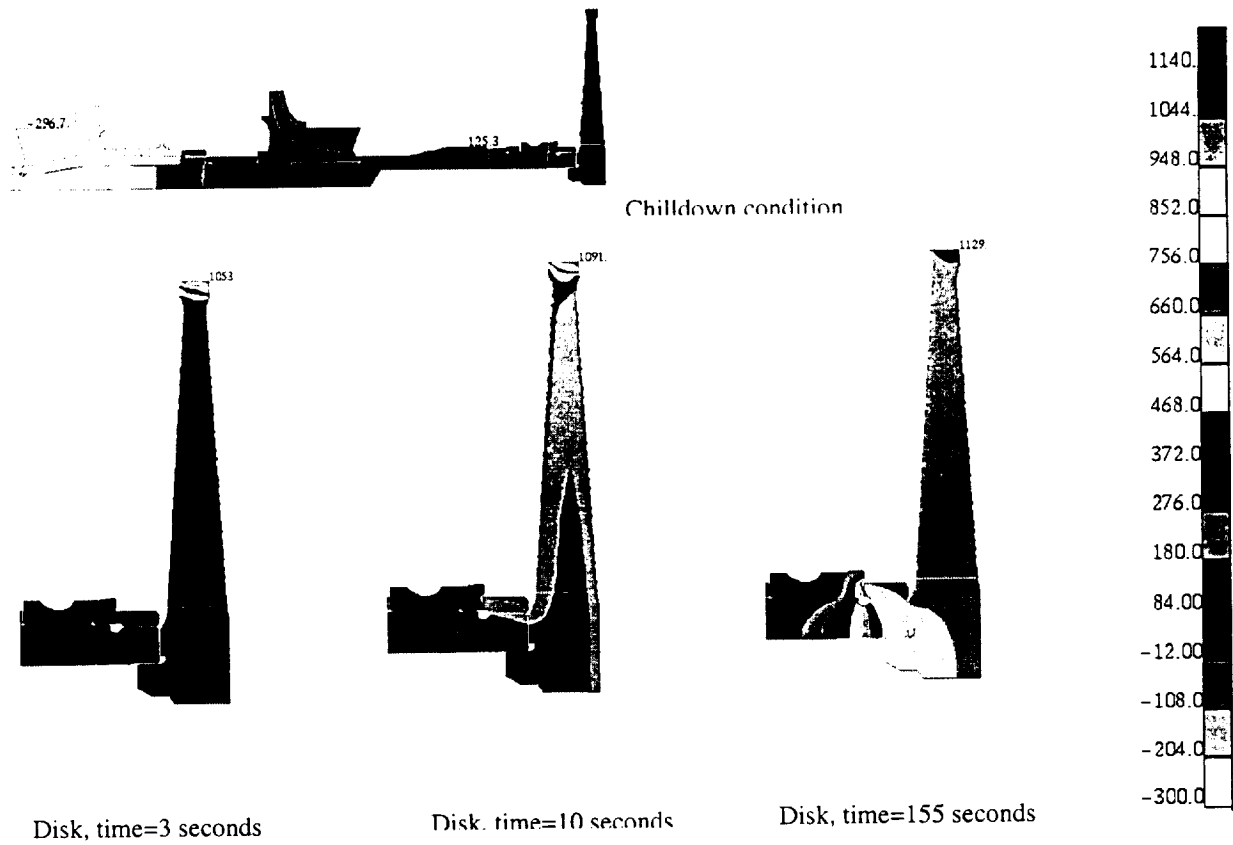


Figure 2 Rotor Model Results

CONCLUSIONS

Some of the areas of uncertainty included turbine housing cavity and heat shield disk cavity because of the unknown gas generator combustion gas properties. Conservative assumptions used to bind the possibilities. Heat shield design minimizes impact of unknown environments.

Heaters are used during the engine pre-fire stage to prevent the fuel from reaching freezing temperature (-40°F).

Average surface temperature was calculated in support of the engine aft compartment ambient assessment. This is an X34 system requirement. Environments of Hot & Cold day were used in support of this task.

The analysis results were used to support the structural analysis and the analysis of the post engine fire heat absorbed by the oxygen trapped in the pump to help size relief lines and valve.